Retrieval of Thermospheric Molecular Oxygen Profiles from Solar and Stellar Occultation Measurements

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SUSIM Solar Occultation Dataset

Since October 1991, SUSIM has performed solar occultation measurements one day per week, measuring full-disk solar extinction as a function of tangent altitude at 141, 160 and 171 nm, with a spectral resolution of 1.1 nm. To date, ~ 1000 occultations through 1997 have been analyzed, but over 1500 total profiles through 2004 are available for analysis. The data span a wide range of solar and geomagnetic activity, and latitudes up to 7
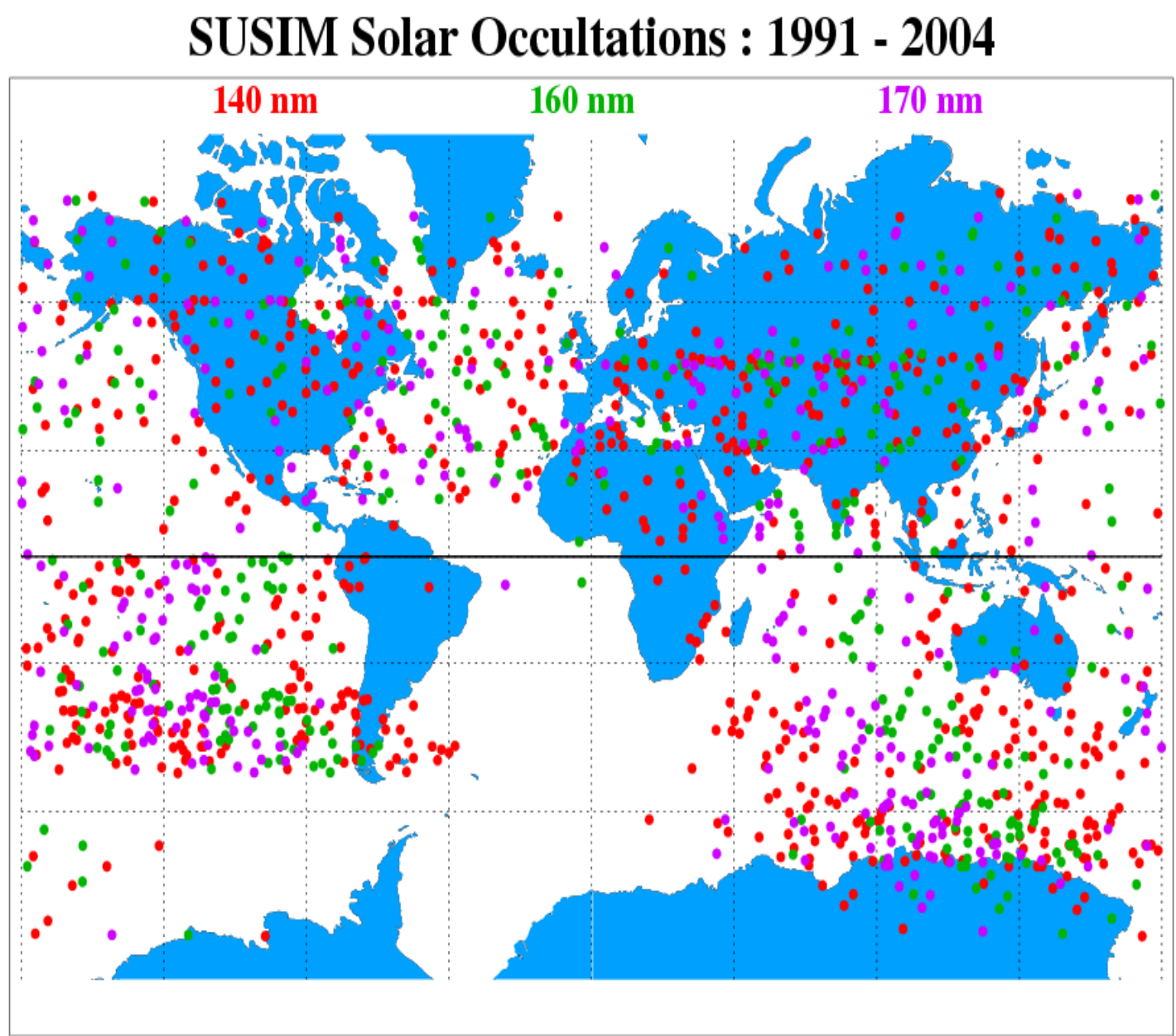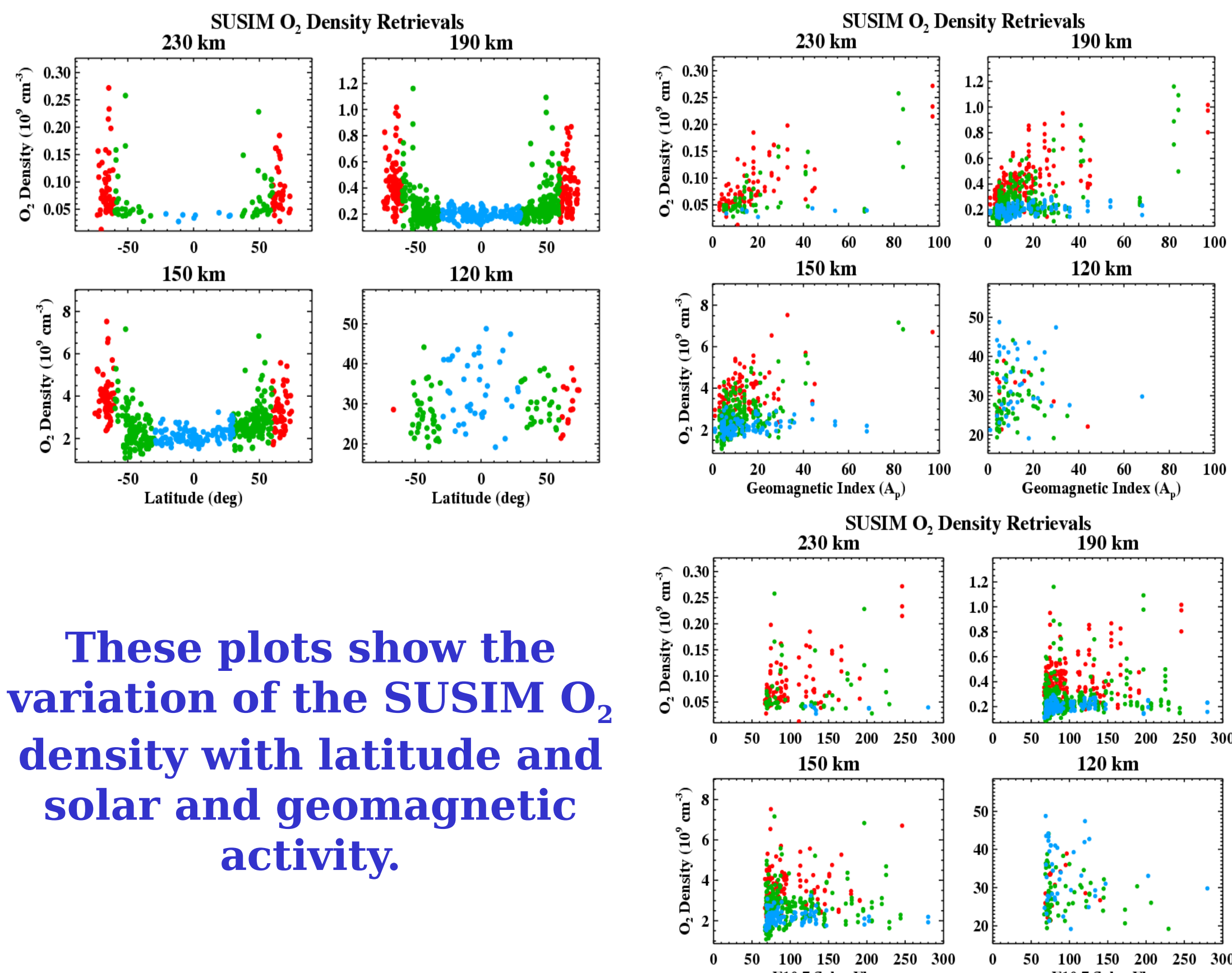

Location of SUSIM O$_2$ occultations.
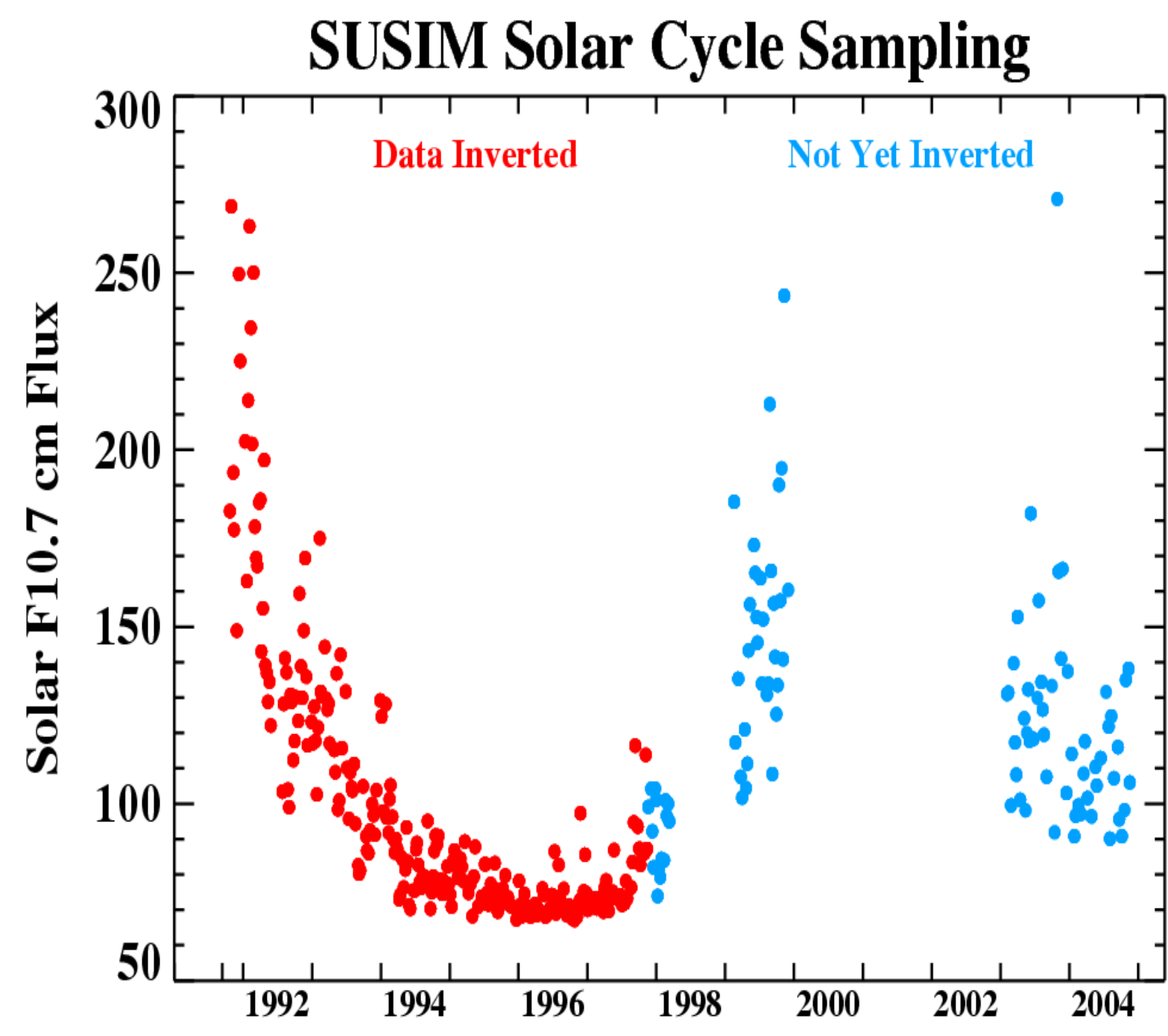
The SUSIM data spans a wide range of solar activity.
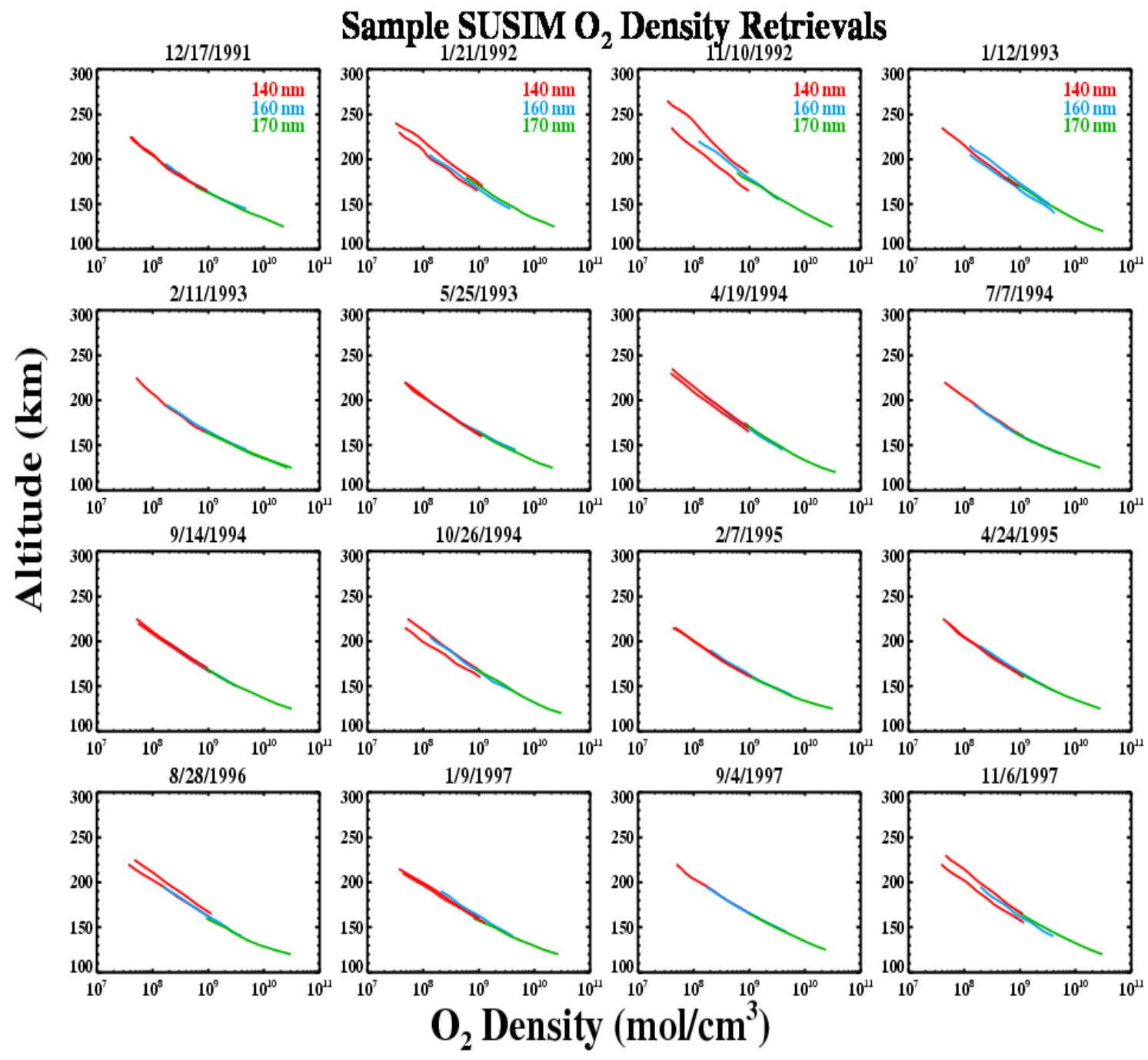
SUSIM measures 4 sequential occultations on a given day using 3 wavelengths. 141 nm is usually repeated.

These plots show the variation of the SUSIM O$_2$ density with latitude and solar and geomagnetic activity.
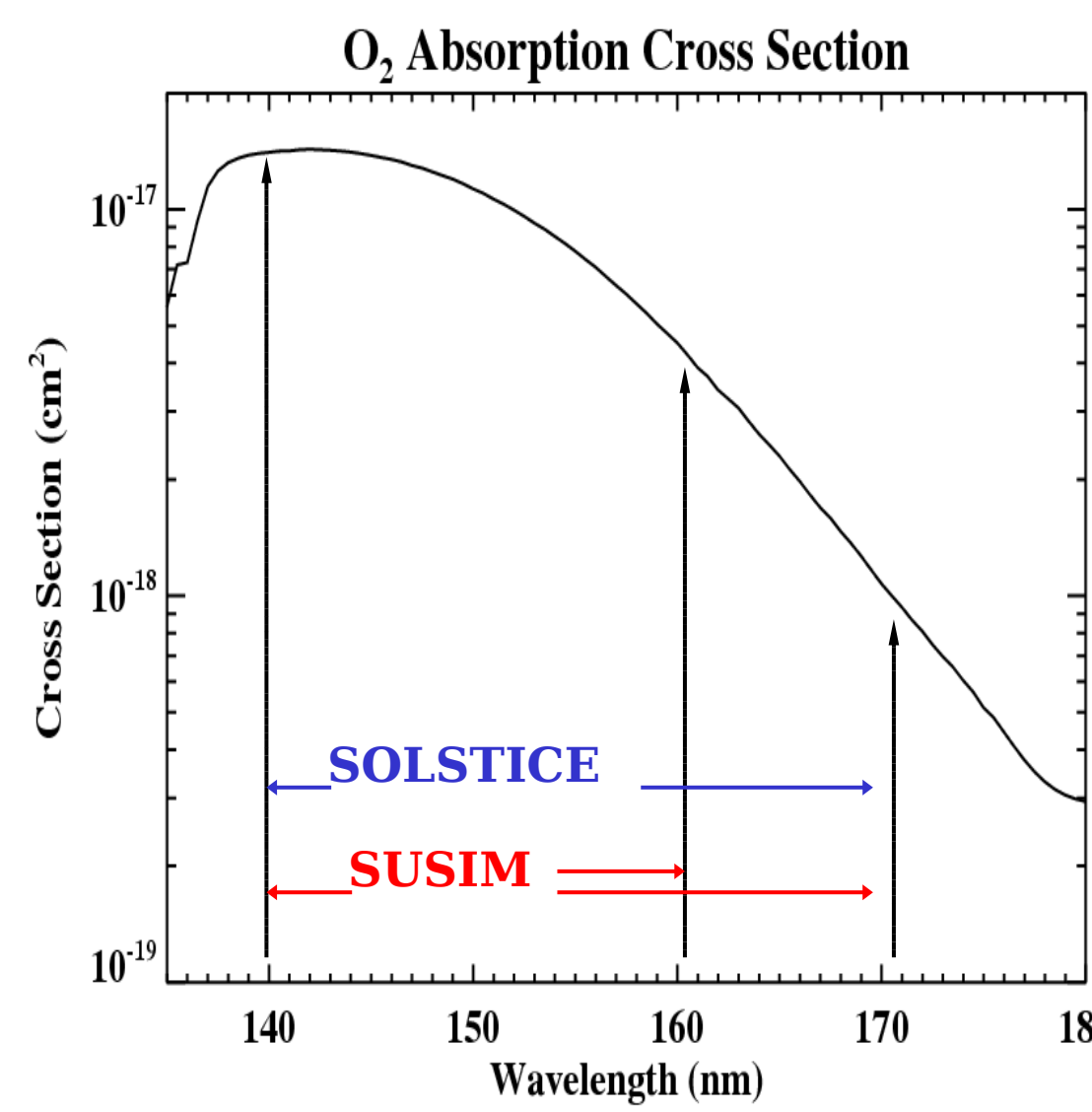
Abstract

We present two new data sets of thermospheric molecular oxygen (O$_2$) density profiles retrieved from both solar and stellar occultation measurements. The solar occultation measurements are made by the Solar Ultraviolet Spectral Irradiance Monitor (SUSIM) instrument onboard the UARS satellite, and the stellar occultations are obtained from the SOLar STellar Irradiance Comparison Experiment (SOLSTICE) on the SORCE satellite. Both instruments are nominally solar experiments whose primary mission is to measure the magnitude and variability of the UV solar irradiance. However, a simple extension of either the operational solar measurements (in the case of SUSIM) or the daily stellar calibration sequence (in the case of SOLSTICE) provides an opportunity to remotely sense the Earth's upper atmosphere using occultation. By measuring the attenuation of sunlight or starlight in the O$_2$ Schumann Runge continuum (140 – 170 nm), it is possible to retrieve density profiles of O$_2$ between approximately 120 and 250 k

Motivations

- O$_2$ is the 3rd most abundant thermospheric constituent yet its abundance and variability is not well known. Thermospheric O$_2$ data are particularly limited at high latitudes under solar maximum conditions.

- There are unresolved discrepancies between existing in situ (mass spectrometer) and remote sensing (occultation) measurements.

- Comparison of these measurements with 2D models can help address questions about the relative importance of chemistry and dynamics in the O$_2$ distribution.

- Improved O$_2$ measurements over a wide range of geophysical conditions can provide important constraints on both GCMs and empirical models such as MSIS.

Retrieval Algorithms

Both instruments measure atmospheric transmission at multiple wavelengths in the Schumann Runge continuum to maximize the retrieval altitude range.
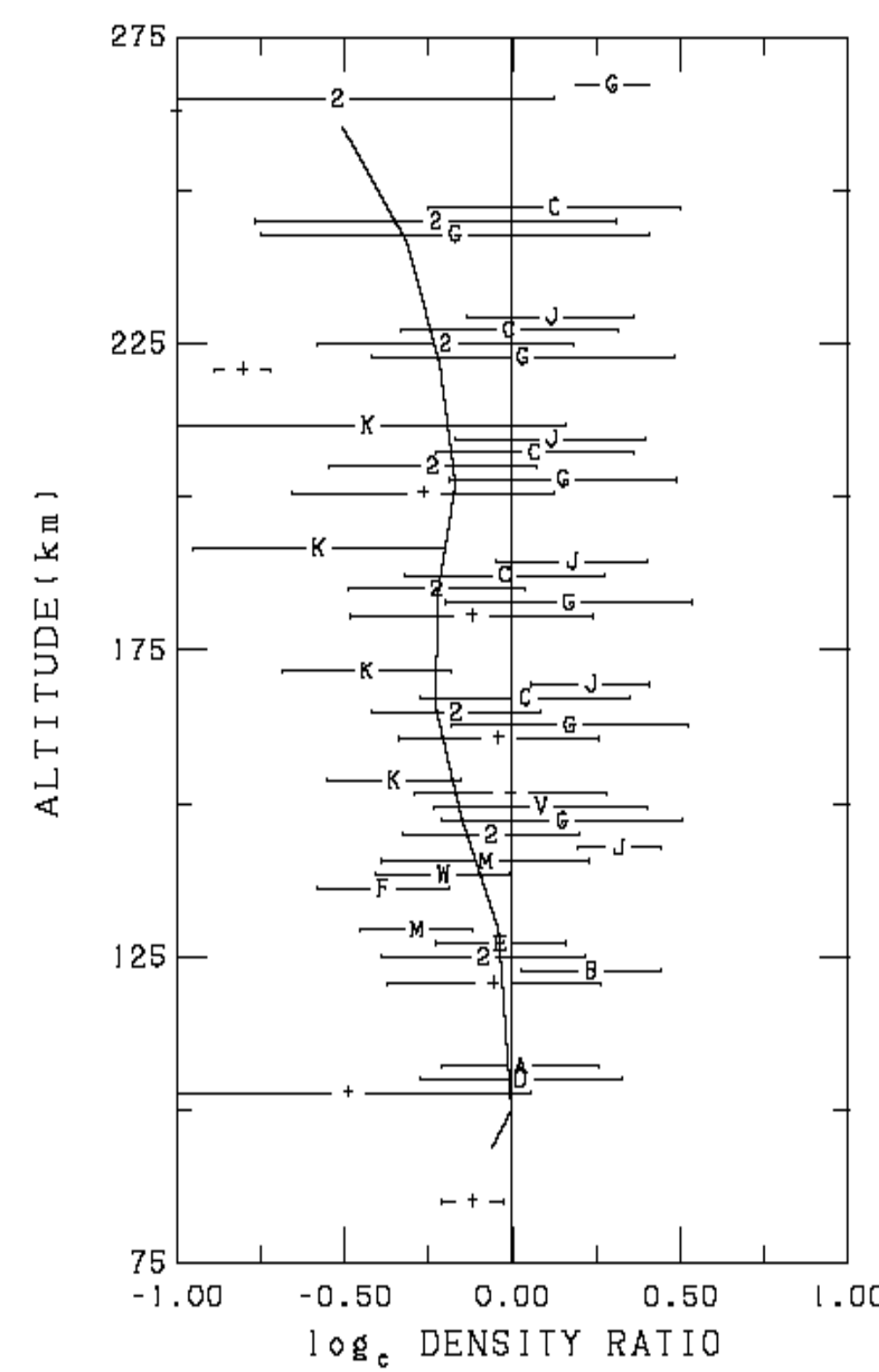
Retrieval of O$_2$ density profiles from the SUSIM and SOLSTICE transmission measurements is achieved using an optimal estimation inversion algorithm, similar to the operational algorithms used for the POAM II and III multi-wavelength solar occultation instruments.
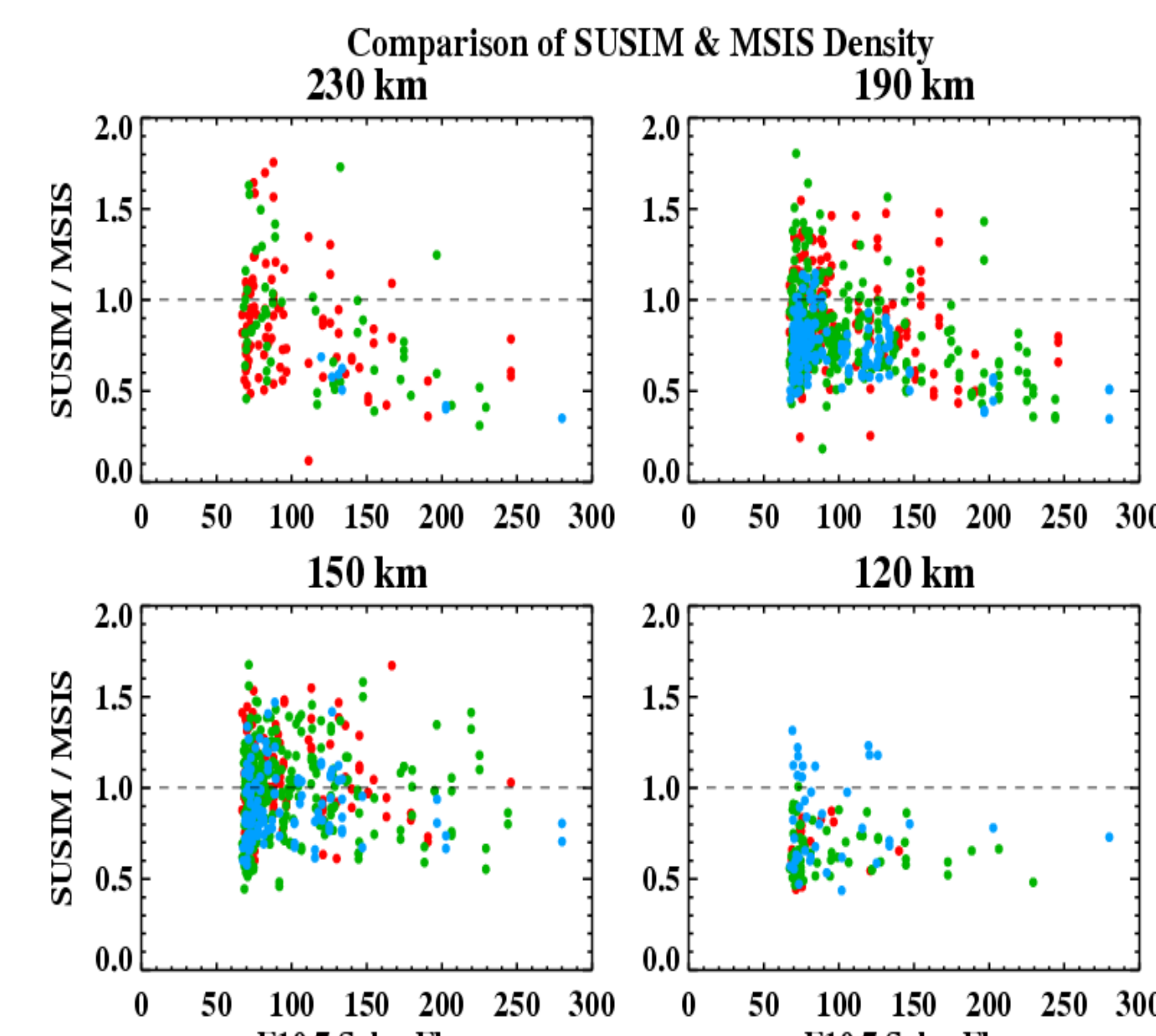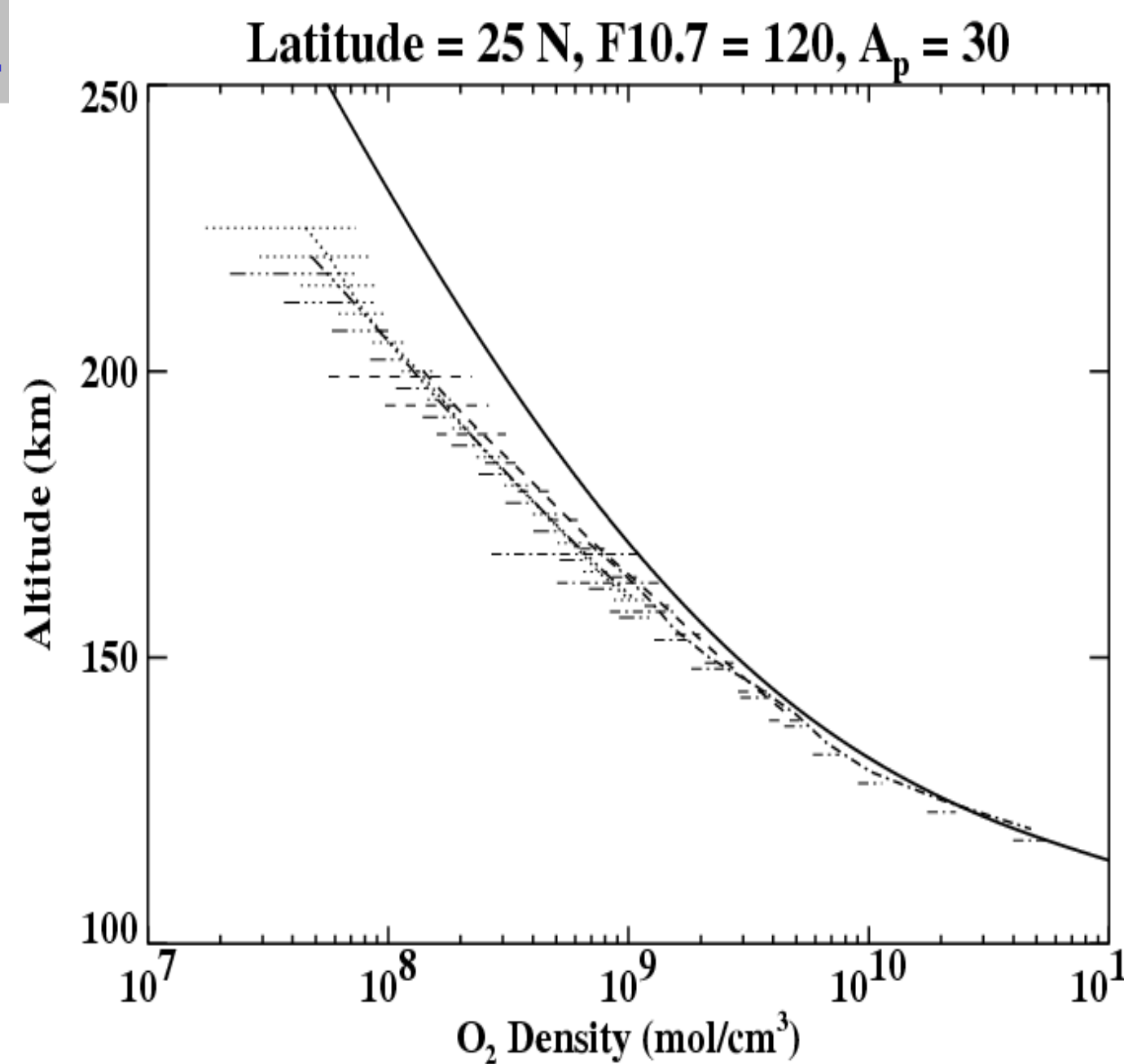

O$_2$ spectroscopy and measurement wavelengths.

For a finite source (full or partial sun) the measured signal represents a spatial and spectral integration of the input source function, weighted by the atmospheric transmittance:

$$S = \int_{Dn} dn \, Q(n) \int_{DW} dW \, H(W) I(n,W) t(n,W)$$

$Q(n)$ — instrument optical bandpass function
$H(W)$ — instrument field of view (Ω = solid angle)
$I(n,W)$ — unattenuated solar or stellar flux
$t(n,W)$ — monochromatic atmospheric transmittance

Normalizing by the exoatmospheric signal $S_\infty = S(\tau \to 1)$, and integrating out the azimuthal dimension yields transmission as a function of tangent altitude z_t:

$$T(z_t) = \frac{1}{C} \int_{z_t \pm Dz} dz \, H(z - z_t) G(z - z_t) \langle t(z) \rangle$$

where

$$C = \int dz \, H(z - z_t) G(z - z_t)$$

$$\langle t(z) \rangle = \int dn \, Q(n) I_0(n) t(n,z) / \int dn \, Q(n) I_0(n)$$

Stellar occultation utilizes a point source, so

$$H(z - z_t) = G(z - z_t) \otimes d(z - z_t) \quad \text{and} \quad T(z_t) \otimes \langle t(z_t) \rangle$$

The spectrally averaged transmittance is related to the O$_2$ density profile n_{O_2} through:

$$\langle t(z_t) \rangle = \int dn \, Q(n) I_0(n) \exp\left[-\int ds \, s_{O_2}(T(s)) \, n_{O_2}(s)\right]$$

$$\approx s_{O_2}^{eff}(\overline{T}(z_t)) N_{O_2}(z_t)$$

where

$N_{O_2}(z_t) = \int ds \, n_{O_2}(s)$ — O$_2$ slant column density
$s_{O_2}^{eff}(\overline{T}(z_t))$ — O$_2$ effective cross section
$\overline{T}(z_t)$ — Slant path temperature

The O$_2$ density profile is retrieved directly from the SUSIM and SOLSTICE transmission measurements using an optimal estimation inversion algorithm, similar to the operational algorithms used for the POAM multi-wavelength solar occultation instruments.

The temperature-dependent O$_2$ cross sections come from Gibson S.T. et al. [1983] and for the SUSIM retrievals we use the solar limb darkening coefficients from Brueckner and Moe [1972].

Comparison between SUSIM and MSIS

Sample SUSIM O$_2$ profiles (overlapping dashed and dotted lines) compared to MSISE-90 model (solid line) on a given day. Divergence above 150 is typical.

Comparison of various O$_2$ data sets to MSISE-90 values. "2" represents SUSIM, "K" is SMM. Solid line is NRLMSISE-00.

Dependence of SUSIM - MSISE-90 ratio on solar activity. Note increasing divergence with 10.7 cm flux above 150 km.

Preliminary Validation

A search for coincident SUSIM / SOLSTICE measurements is underway. This plot shows locations of SUSIM and SOLSTICE occultations within one day of each other in 2004. These are potential validation opportunities.

The SOLSTICE instrument on UARS also made stellar occultation measurements.

These plots compare O$_2$ retrievals obtained from SUSIM and SOLSTICE on UARS.
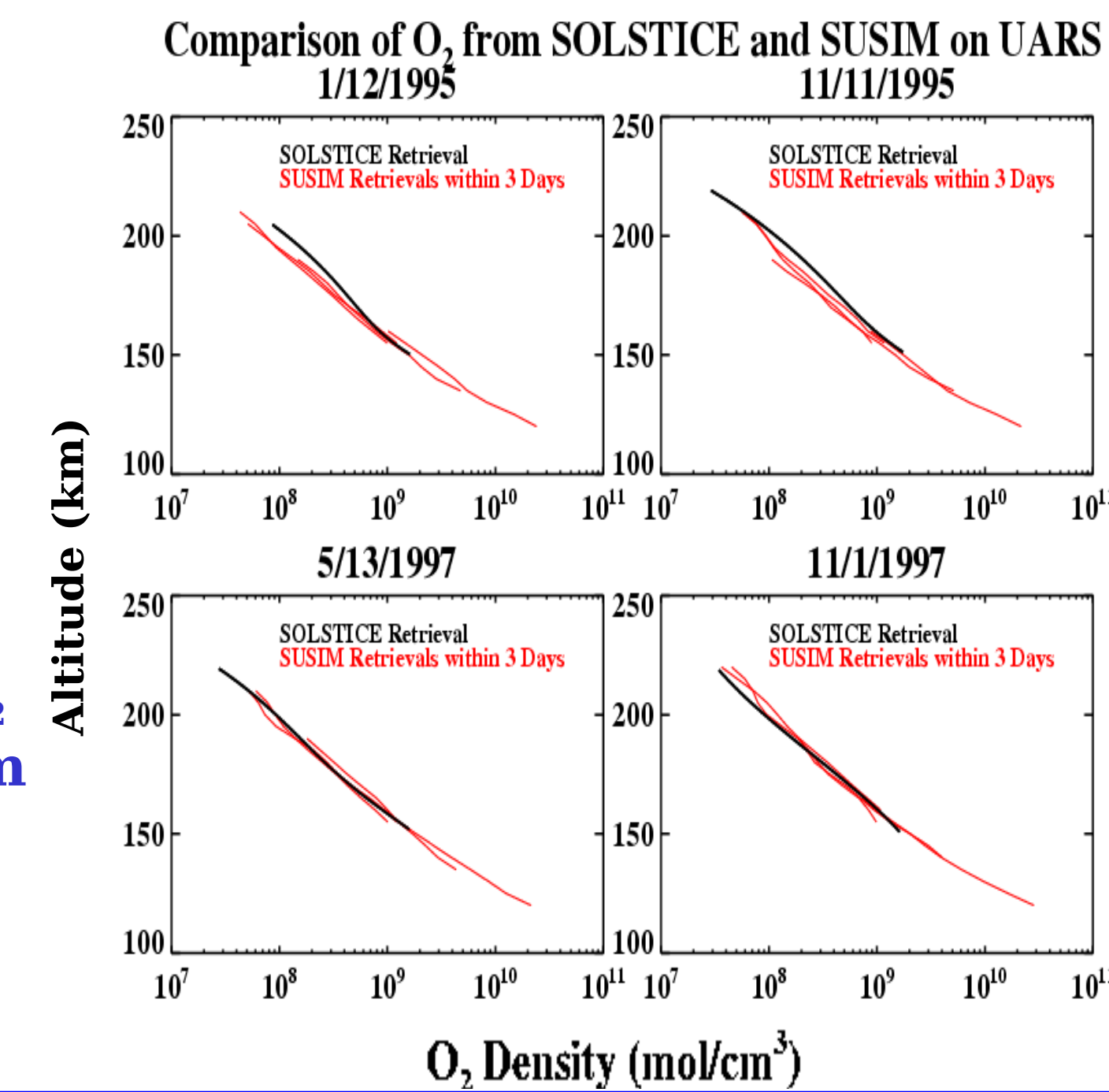
SOLSTICE Stellar Occultation Dataset

Two identical SOLSTICE instruments have been operating onboard the SORCE satellite since January 2003. In the first year of operation approximately 100 occultation events were obtained but since May 2004 these measurements have been made on a routine basis, approximately 10 times per week. Currently, over 600 occultations are available for analysis. Generally the two instruments measure simultaneously at 141 and 171 nm to provide a composite O$_2$ retrieval. Spectral resolution...
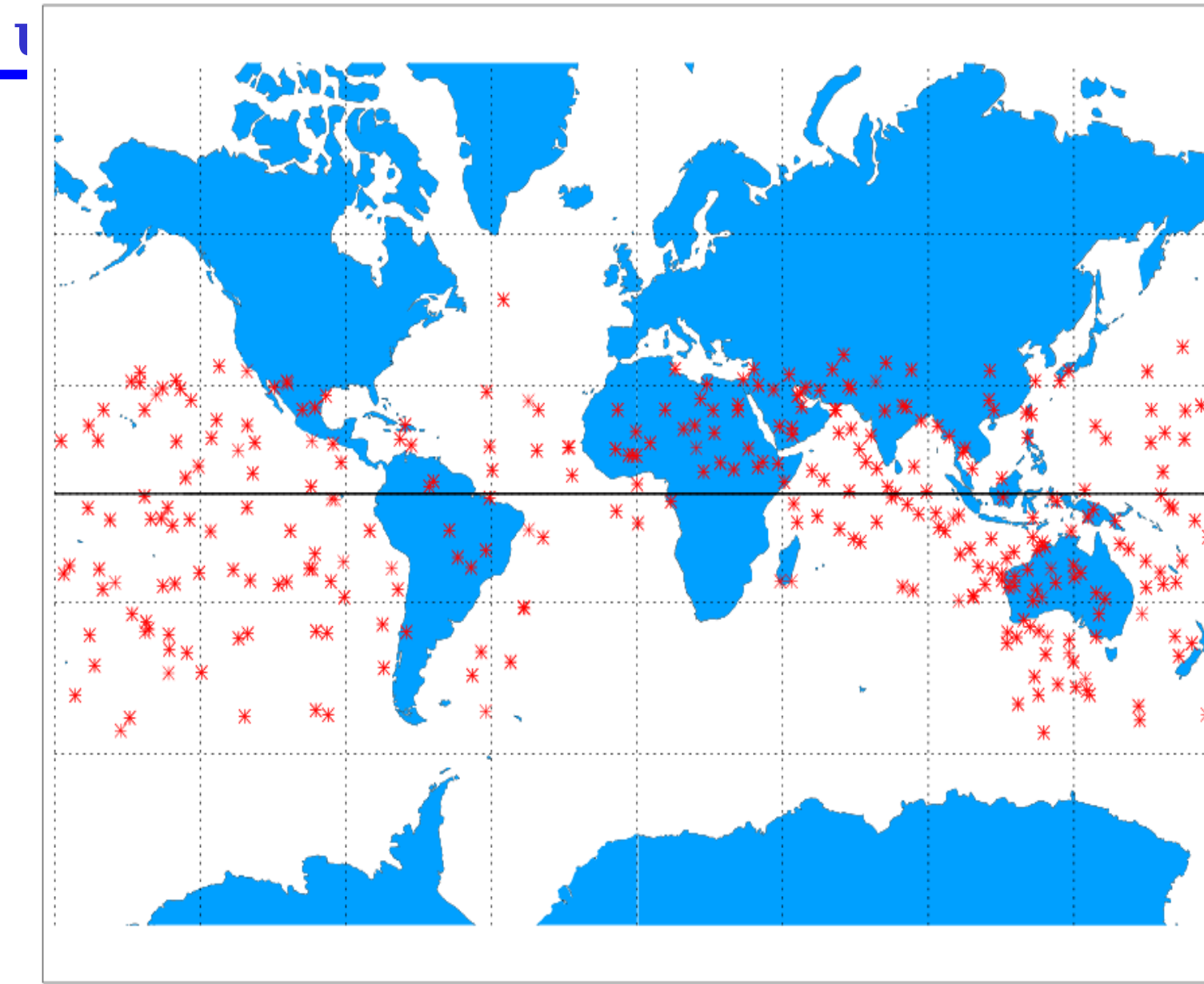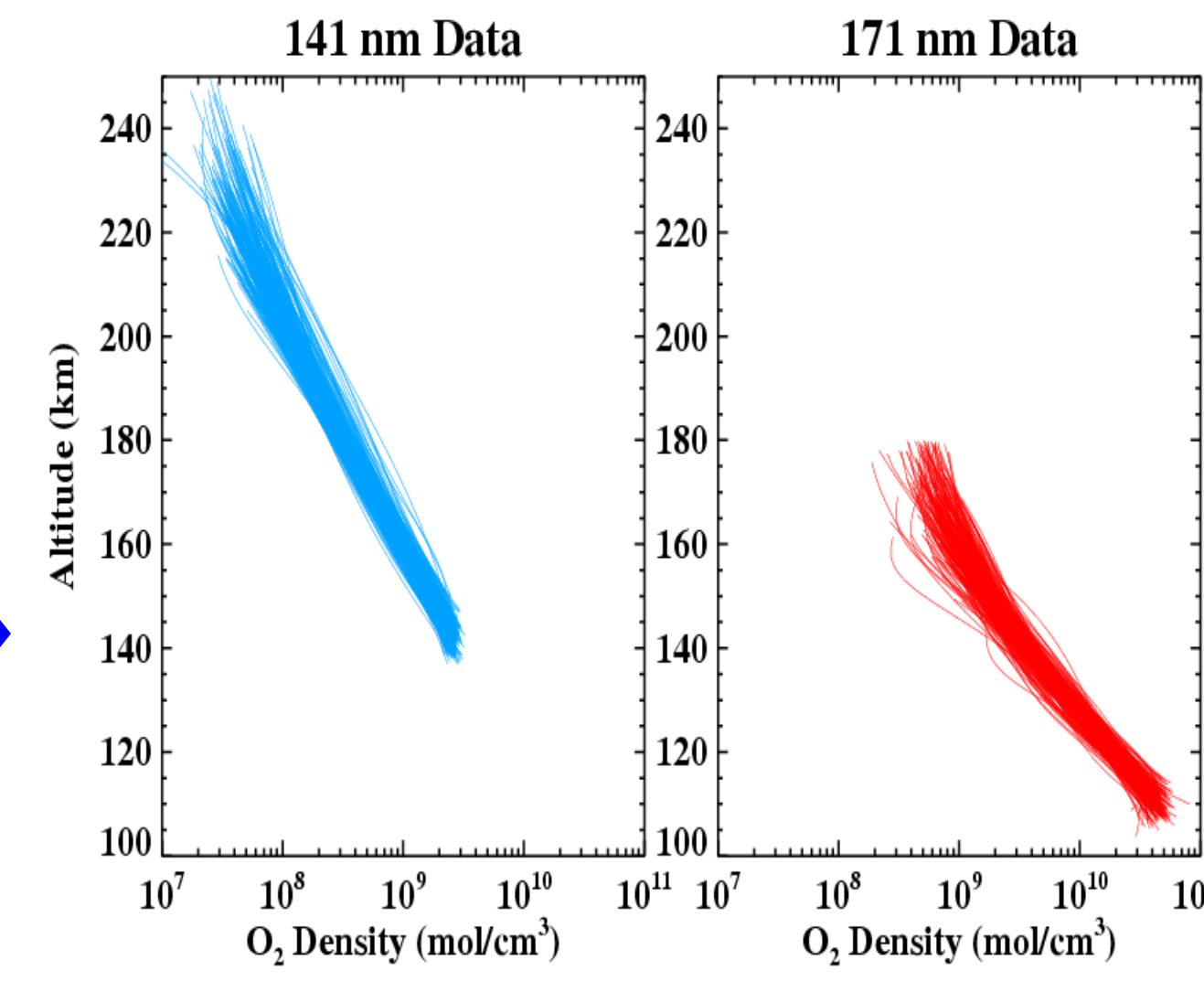

Location of SOLSTICE O$_2$ stellar occultations.
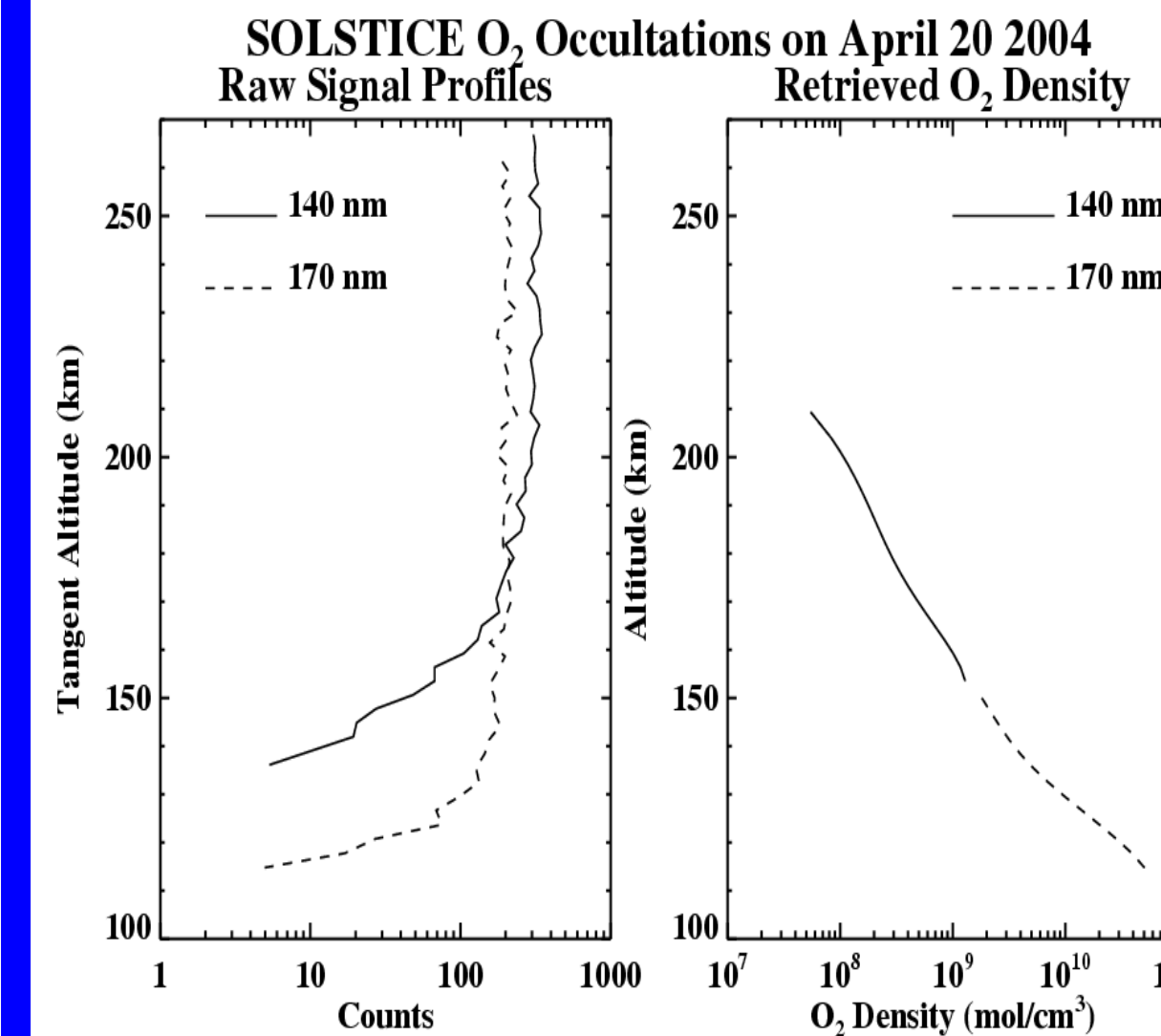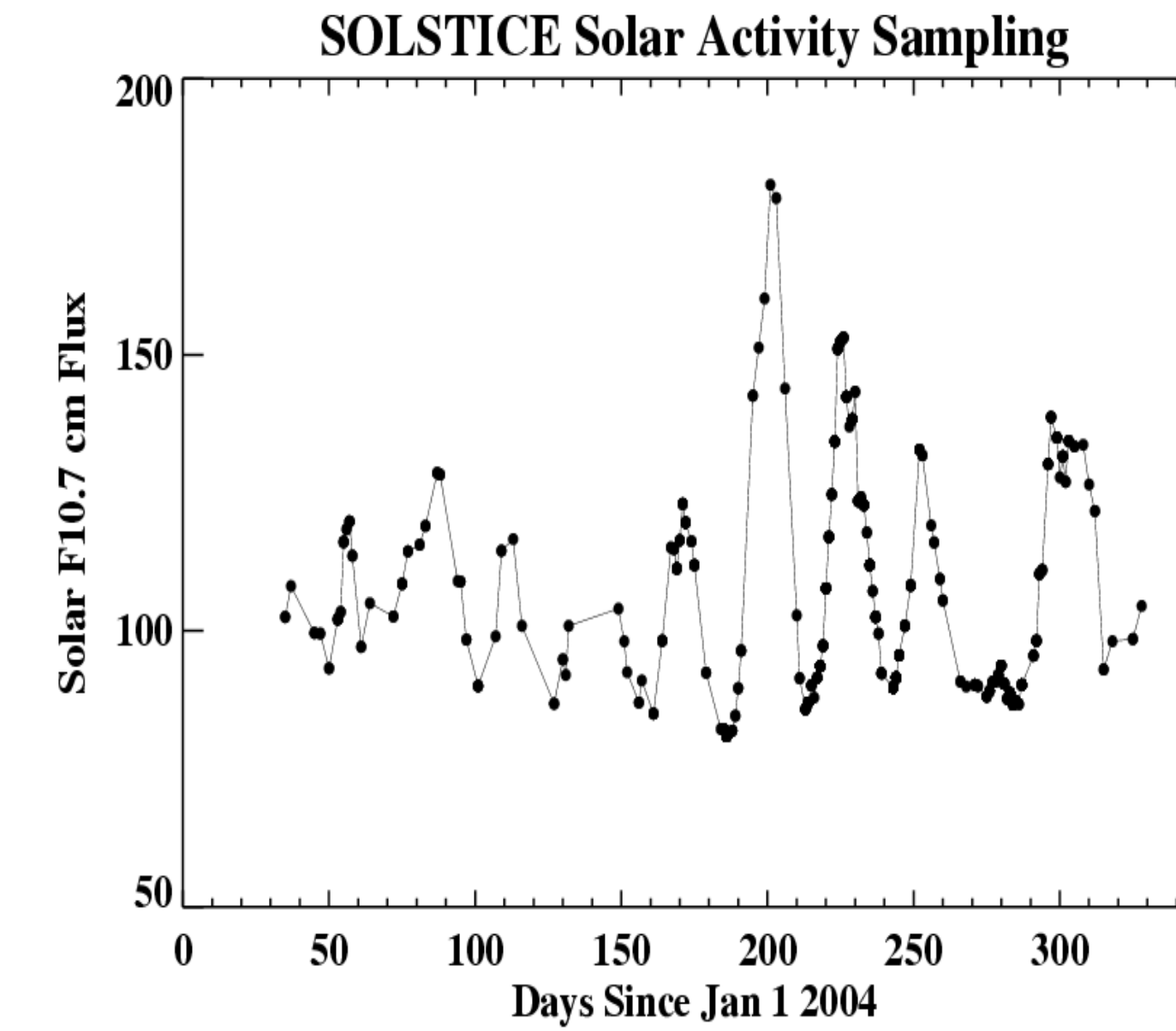
Simultaneous scans at 141 and 171 nm yield a composite O$_2$ profile.

O$_2$ profiles retrieved from all 141 and 171 nm occultations

Consistency of 141 and 171 nm retrievals on some sample days.